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The Effect of Compression on Individual Pressure Vessel Nickel/Hydrogen Components

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THE EFFECT OF COMPRESSION OF INDIVIDUAL PRESSURE VESSEL

NICKEL/HYDROGEN COMPONENTS

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SUMMARY

Compression tests were performed on representative Individual Pressure Vessel (IPV) Nickel/Hydrogen cell components and cell assemblies in an effort to better understand the effects of force on component compression and the interactions of components under compression. It appears that the separator is the most easily compressed of all of the stack components. It will typically partially compress before any of the other components begin to compress. The compression characteristics of the cell components in assembly differed considerably from what would be predicted based on individual compression characteristics. Component interactions played a significant role in the stack response to compression. The results of the compression tests were factored into the design and selection of Belleville washers added to the cell stack to accommodate nickel electrode expansion while keeping the pressure on the stack within a reasonable range of the original preset.

INTRODUCTION

The overall objective of the Lewis Research Center battery program is to advance the technology of nickel/hydrogen cells and batteries for use as energy storage systems for low-earth-orbit (LEO) applications. As part of this effort IPV cell designs were evaluated and design modifications have been proposed that accommodate the needs of the individual components. This should lead to improved cell operating characteristics and extended cycle life at deep depths of discharge (DOD) (ref. 1).

Electrochemically impregnated nickel electrodes expand considerably when cycled (ref. 2). This could lead to excessive compression of other stack components and adversely effect cell performance. Excessive pressure on the stack can conceivably lead to the loss of electrolyte from the separator and result in high resistance. In an extreme case, nickel electrode expansion has resulted in core rupture and cell failure (ref. 3). This mode of failure could be eliminated by incorporating an allowance for electrode expansion in the cell core. Advanced cell designs proposed at the Lewis Research Center recommend the use of Belleville washers to provide such an accommodation. The accommodation required of the Belleville washers will depend upon the relative deflection of the components in the stack as well as the projected expansion of the nickel electrodes. Compression behavior was studied in an effort to expand the limited data base on the effects of force versus compression and to help identify the required Belleville washer properties.

This paper presents test data from compression measurements performed on individual cell components and information relevant to the design and selection of the Belleville washer used to accommodate electrode expansion. The electrodes, gas screens and separators tested represent standard state-of-the-art Air Force design components. Some experimental separators, developed as part of the on-going component technology efforts at the Lewis Research Center, were also tested. In selected cases, the compression studies were performed with representative multi-component stacks.

EXPERIMENTAL

Cell Components

All of the cell components used in the compression tests were of the Air Force type, pineapple slice design. Descriptions of the cell components used for the compression tests follow.

Nickel Electrodes

The compression characteristics of two types of nickel electrodes were evaluated. The plaque in both electrodes was fabricated by the dry powder process and had a nickel screen substrate. The plaque mechanical strength was 550 psi and the average pore size was 13 μm. The electrodes differed only in impregnation method. The Pickett and Bell processes were evaluated. Both types of electrodes were .030 in. thick.

Hydrogen Electrodes

The hydrogen electrodes used were of the standard Air Force design. The electrodes consisted of a platinum/teflon catalyst mixture bonded to a photochemically etched nickel substrate. The electrodes were backed with a gas permeable, porous teflon membrane. The electrodes were loaded to approximately 1.24 g/in^2. Total electrode thickness was .006 in.

Separators

Six types of separators were tested. The state-of-the-art materials tested were standard fuel cell grade asbestos (FCGA) and zirconium oxide cloth (Zircar Cloth). Beater treated asbestos (BTA), reconstituted fuel cell grade asbestos with 5 percent butyl latex binder added, served as the Lewis standard. Potassium titanate (PKT), PKT deposited on zircar cloth, and a separator made of 80% PKT and 20% ZrO_2 were the experimental separators tested. The advanced cell designs proposed at Lewis require high bubble pressure separators. All of the experimental materials tested exhibit high bubble pressure (>15 psi) and are potential replacements for the asbestos presently used. Complete descriptions and information on separator properties have been previously reported in references 4 and 5.

Gas Screens

The gas screen used in this test was obtained from Eagle Picher. It was a polypropylene screen, .022 in. thick.

Test equipment

The instrument used to evaluate the compression characteristics of the cell components was a Geotest-Unconfined S-2000. It consists of a double proving ring capable of 1500 lbs, a strain dial indicator, a dial pointer arm and other accessories. Readings on the proving ring dial are converted to load by use a calibration chart characteristic of each proving ring. Load is applied by turning an aluminum hand crank connected to a gear box that drives the lower platen against the stationary upper platen.

Measurement Procedures

The testing was divided into two phases. Each component was tested individually and assembled in a stack consisting of three sets of components. In the individual test each component was tested both dry and wet with KOH. For the stack assembly compression tests, the components were modified, as shown in figure 1, to allow measurement of separator and electrode compression independent of the other stack components. Portions of the electrodes and separators were removed to allow introduction of a feeler gauge into the completed assembly for measurement of the total compressed thickness of the electrodes and separator. Figure 1 also shows the component assembly sequence. As with the electrodes, stack compression measurements were made on a representative assembly both dry and wet with KOH. The dry stack was preloaded to 5 psi, then vacuum backfilled with KOH and the loading remeasured. Data on force versus compression were taken.

RESULTS AND DISCUSSION

Separators

Plots of compression versus force for dry separators are shown in figure 2. The dry thickness of the separators varied from .006 to .022 in. therefore, in order to measure relative compressibilities the compression data were normalized based on thickness. The normalized results are summarized in table I. In general the asbestos and PKT separators were more compressible than those made with the zircar cloth.

The compression characteristics of BTA, zircar cloth and PKT on zircar cloth were evaluated wet with KOH as well as dry. Comparison of figures 2 and 3 shows the behavior patterns of these separators in the wet versus dry states. The PKT on zircar cloth and the zircar cloth show similar behavior in the wet and dry states, with the PKT on cloth showing a somewhat greater change in compression characteristics in the wet versus dry states than the zircar cloth alone. This can be explained by the fact that the zircar cloth is dimensionally stable in KOH. Conversely the PKT coating expands a few mils and the BTA separators typically see a 50 percent increase in thickness when wet in the uncompressed state. This has the effect of making the BTA and coated zircar more compressible in the wet state.

Electrodes and Gas Screens

Plots of compression versus force for the two kinds of nickel electrodes tested, the standard hydrogen electrode, and the gas screen are shown in figure 4. The normalized electrode and gas screen data are included in table I. Both nickel electrodes show similar behavior. In the individual component tests the hydrogen electrode and gas screen rank in compressibility behind the nonzircar separators and before the nickel electrode. There were no differences in the compression characteristics of wet and dry electrodes.

Stack Tests

Prediction of stack compression based on individual component characteristics would yield the compression curve shown in figure 5. The compression characteristics of an actual three pair component stack were evaluated. For comparison to the predicted curve, the deflection values were divided by three to give the actual total curve shown in figure 5. The initial stack compression that would be expected with the settling of the components was accounted for in the establishment of a reference point from which to begin measurements as a result, this does not show up in the data plot. The total stack compressed much less than predicted, in fact, in some cases, the compression characteristics of the total subgroup of components in assembly was less than that of the individual components. This illustrates the effect and importance of component interactions in the stack assembly. The individual component compression characteristics were measured between two flat plates which provided no interaction with the components whereas, in the stack the component irregularities interact to yield much less component deflection at equal force levels.

It was difficult to isolate components within the stack assembly to determine the degree and order of compression of the individual components in the assembly. Figure 6 shows the curves from an attempt at measuring the compression of one group of electrodes and the BTA separator between them as the entire stack was compressed. Based on this data and some additional attempts at isolating components in assembly it is postulated that the separator is the first component to compress. It appears to partially compress before any of the other, less compressible, components begin to compress. In figure 6, the inflection point in the separator and electrode curve at approximately 5 psi appears to be the point where the separator alone ceases compressing and the electrodes begin to compress. The difference between the curves for the total stack and separator and electrodes represents compression of the gas screens and deflection from the meshing of the components beyond those in the subgroup.

Since nickel hydrogen cells are constructed and preloaded in the dry state, then backfilled with KOH, measurements of force and compression on a dry stack and that same stack wet with KOH were taken. As expected, there were no differences between the wet and dry stacks. Since the separator was restrained in the assembly and not allowed to swell freely its compression characteristics did not vary greatly in the wet versus dry states as was observed in the individual component tests. At 5 psi all of the compression appears to be taken up by the separators.

Belleville Washers

The advanced designs that have been proposed for Ni/H_2 cells incorporate Belleville washers at either end of the stack specifically designed to compress as the nickel electrode expands in order to maintain the pressure on the stack within a desired range. Nickel electrodes removed from failed cells typically exhibit expansion between 20 and 50 percent (refs. 2 and 3). The design philosophy employed is one of accommodating this expansion and the subsequent needs of the system. Allowing the nickel electrode to expand, and providing sufficient electrolyte to the system might result in longer life and better performance.

The results of the compression studies were factored into the design and selection of the Belleville washers used to accommodate nickel electrode expansion. The stack compression data were used to determine the amount of expansion the Bellevilles would be required to accommodate. Belleville washer parameters were determined for a 125 AH, 4.5" diameter IPV cell with BTA separators. In the stack compression tests at the 5 psi preload level, the separator/electrode combination had compressed two mils, it was assumed that this was all taken up by the separator. Individual component tests showed that the separator will compress approximately 50 percent. This leaves approximately two mils of separator compression available to accommodate nickel electrode expansion. Twenty percent expansion was assumed for the nickel electrodes. For design purposes, all expansion would be accommodated by the separators and washers.

A Belleville washer disk spring with pertinent parameters identified is shown in figure 7. Minimizing the number of washers and the total washer weight resulted in washers with a high h_o:t ratio. Typically when the h_o:t ratio exceeds two, Belleville washers will not operate predictably in series (refs. 6 and 7). As a result, in the design studies the h_o:t ratio was allowed to exceed two but the number of washers was limited to one at either end of the stack. A stop is required with each washer in order to prevent inversion. Stress at point I (fig. 7) was not allowed to exceed 360 000 psi for a washer compressed flat. It was found that 80 percent of the projected expansion could be accommodated with two washers having the following characteristics: De = 2.9 in., Di = 1.77 in., t = 0.038 in., h_o = 0.113 in. These parameters result in a washer with a h_o:t ratio of 2.97 and stress at point 1 equal to 321 000 psi. An individual washer would weigh 0.046 lbs. The force versus deflection curve for this washer is shown in figure 8. The 5 psi preload level is shown on the chart. As the nickel electrodes expand and the washers compress, the force on the stack will range from 5 psi to a maximum of approximately 25 psi. Compression studies performed on an IPV cell have shown that force levels between 5 and 27.4 psi result in no appreciable differences in initial cell performance (ref. 8): without the Belleville washers the force would exceed those values. Should 80 percent of the predicted expansion occur and the washers become flat, the force on the stack would drop to 10 psi. This value is well beyond the required minimum force of 5 psi. Addition of the Belleville washers to the stack should result in improved operation and longer cell life. It is possible that the nickel electrodes in an IPV stack do not fully expand until pressure is relieved, and that the introduction of Belleville washers designed to allow expansion might be detrimental to cell performance. A study is planned to evaluate these effects. The effects of Belleville washer addition will be evaluated in 125 AH, flight weight cells presently being constructed by Eagle Picher. These cells will incorporate the Belleville washers described here as well as other advanced design features proposed by the Lewis Research Center.

CONCLUSIONS

Component interactions lead to differences in the compression characteristics of individual components versus those tested in representative assemblies. The results on components in assembly are more valid when considering compression characteristics in an IPV cell. Based on the compression studies performed, it can be concluded that the separator plays the primary role in stack compression. It appears that the separator alone accommodates the initial force and at force levels greater than 5 psi, the remaining components in the stack begin to compress. The separator behaves differently in the wet and dry states. When allowed to swell freely the separator demonstrated different properties than when constrained. The compression measurements on dry separators are more representative of actual conditions for an IPV nickel/hydrogen cell because the cells are constructed and compressed in the dry state then backfilled with electrolyte.

The compression studies were valuable in understanding component interactions within a stack and determining the required characteristics of Belleville washers incorporated in the stack to accommodate nickel electrode expansion.

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TABLE I. - NORMALIZED COMPONENT COMPRESSION AT VARIOUS FORCE LEVELS

[Percent compression at various force levels.]

Component	Initial thickness, mils	Force level, psi				
		5	10	15	20	25
Separators						
Dry						
Pkt on cloth	22	20	31	40	48	54
Zircar	11	35	52	58	69	--
BTA	7	43	57	79	--	--
FCGA	10	58	73	73	88	--
80:20 Pkt:ZrO_2	9	43	70	79	89	--
PKT	10	43	60	60	70	75
Wet						
PKT on cloth	22	27	42	60	64	68
Zircar	11	35	53	65	85	--
BTA	11	100	--	--	--	--
Electrodes and gas screen						
Nickel	30	23	40	52	--	--
Hydrogen	7	43	67	--	--	--
Gas screen	22	38	55	66	73	--

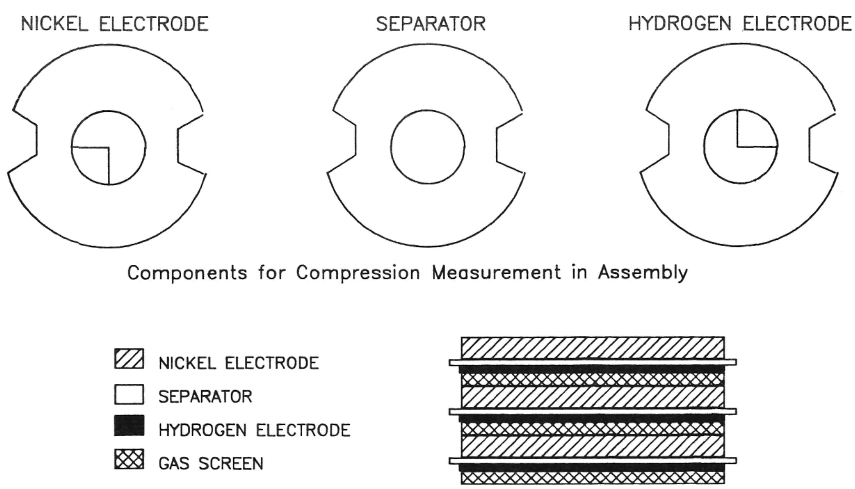

FIGURE 1. - SETUP FOR COMPRESSION MEASUREMENTS IN ASSEMBLY.

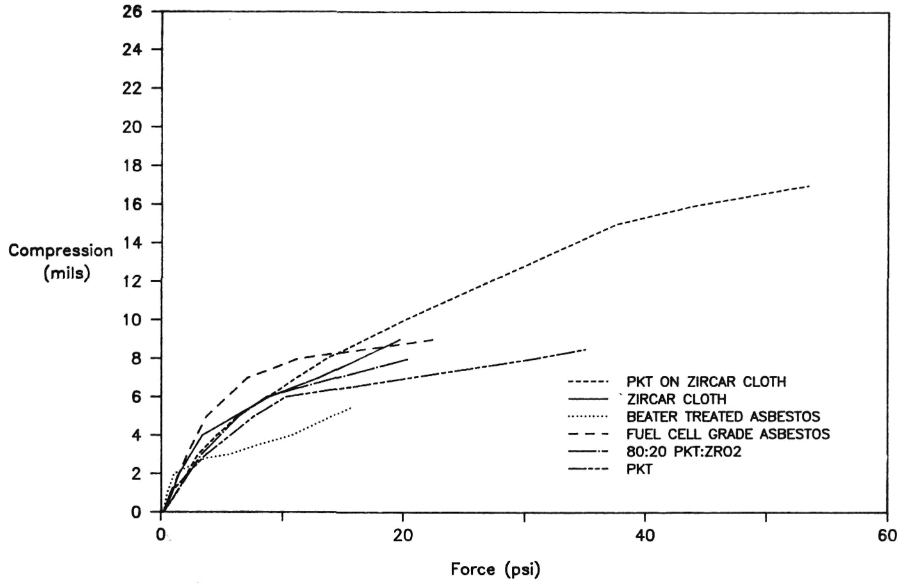

FIGURE 2. - COMPRESSION VERSUS FORCE FOR SEPARATORS IN THE DRY STATE.

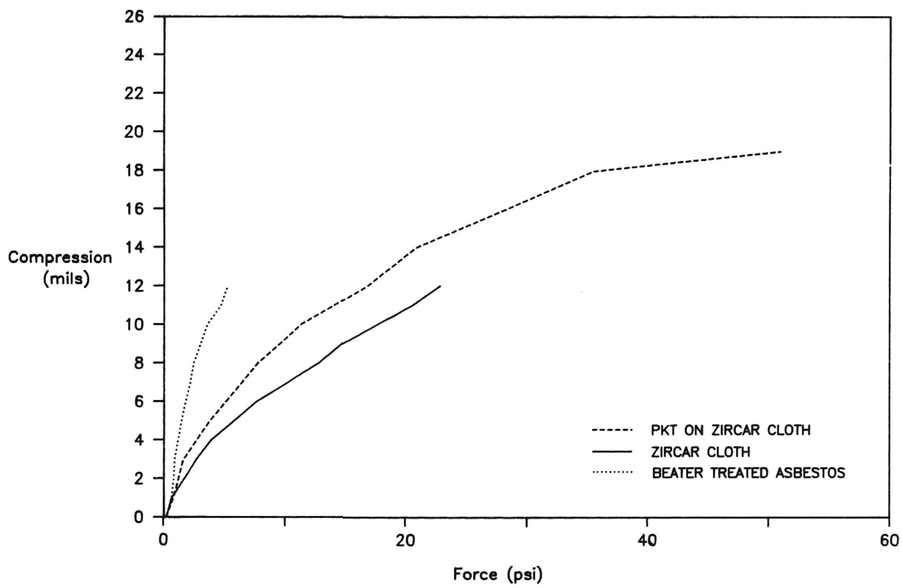

FIGURE 3. - COMPRESSION VERSUS FORCE FOR SEPARATORS IN THE WET STATE.

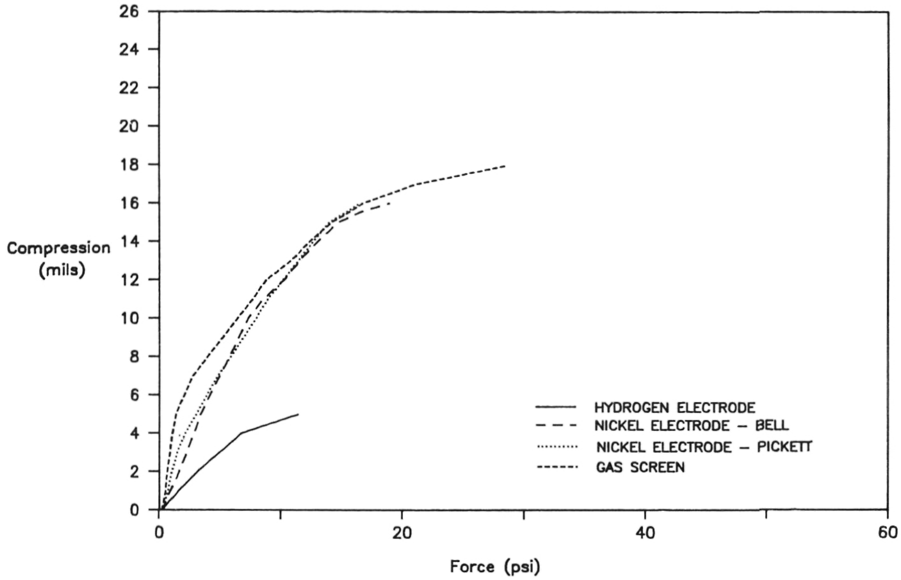

FIGURE 4. - COMPRESSION VERSUS FORCE FOR ELECTRODES AND GAS SCREEN.

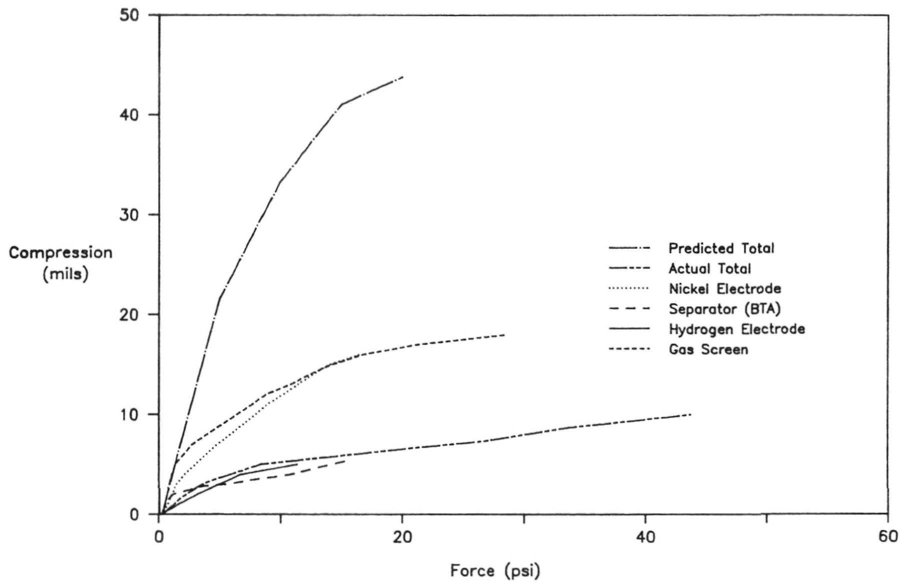

FIGURE 5. - COMPRESSION VERSUS FORCE FOR STACK COMPRESSION - PREDICTED VERSUS ACTUAL.

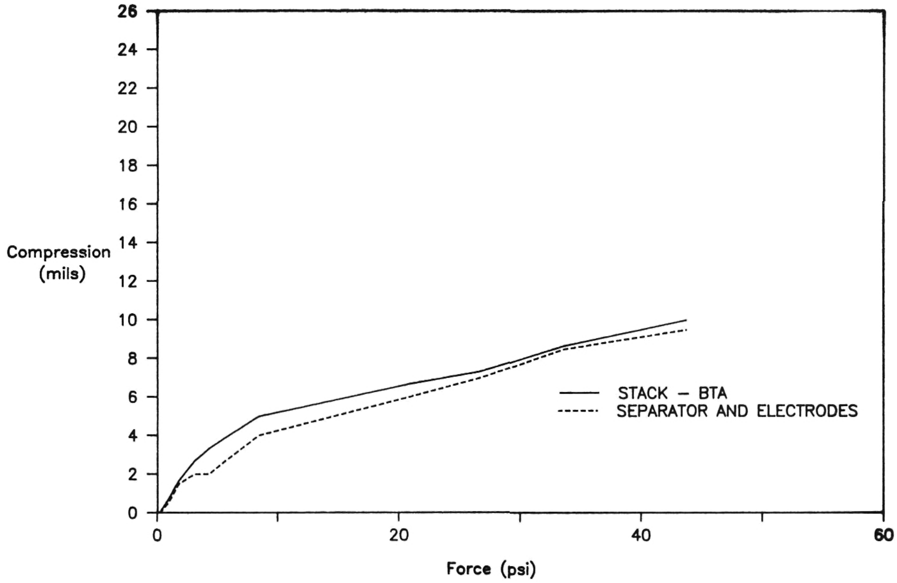

FIGURE 6. - COMPRESSION VERSUS FORCE FOR STACK WITH BTA SEPARATOR.

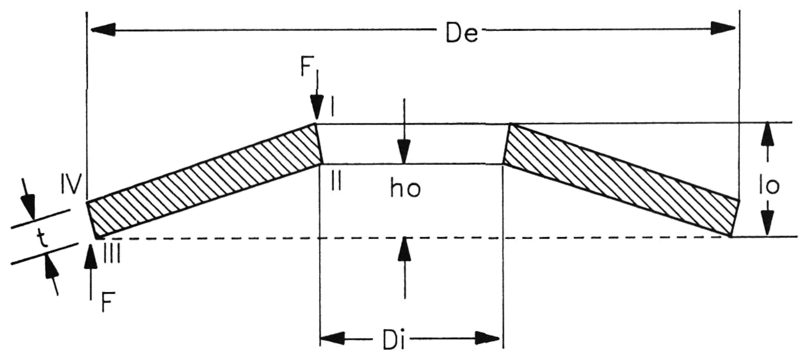

FIGURE 7. - BELLEVILLE WASHER DISK TYPE SPRING.

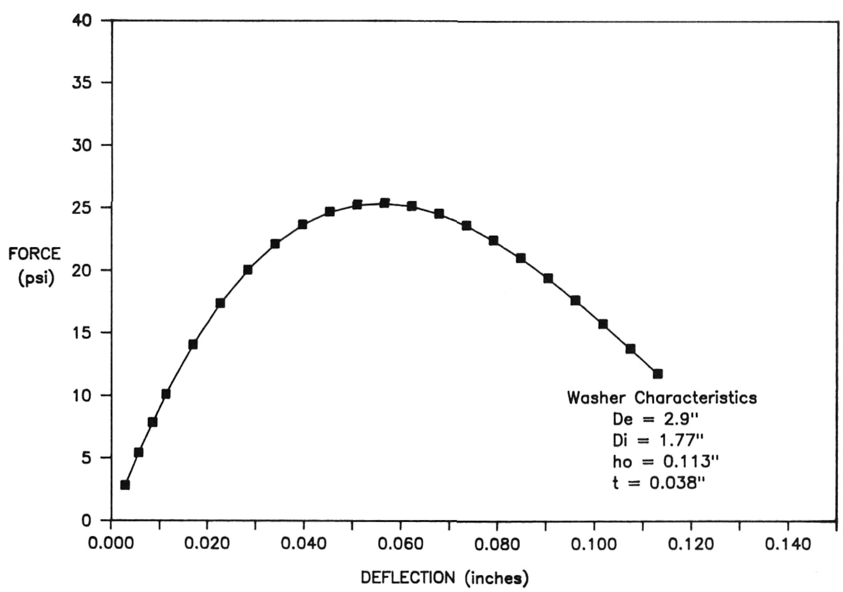

FIGURE 8. - FORCE VERSUS DEFLECTION FOR BELLEVILLE WASHER FOR 4.5-IN.-DIAMETER CELL.

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16. Abstract

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